Heavy Flavor Measurements at RHIC in the Near Future

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Many thanks to the conference organizers

and

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Outline

- **What we have observed**
  - jet energy loss
  - collective flow and partonic collectivity
  - chemical freeze-out near phase boundary
- **Recent heavy flavor results**
  - recent measurements
  - controversies in total cross section results
- **PHENIX & STAR (h.f.) upgrade plan**
- **Summary**

Experimental Results Show

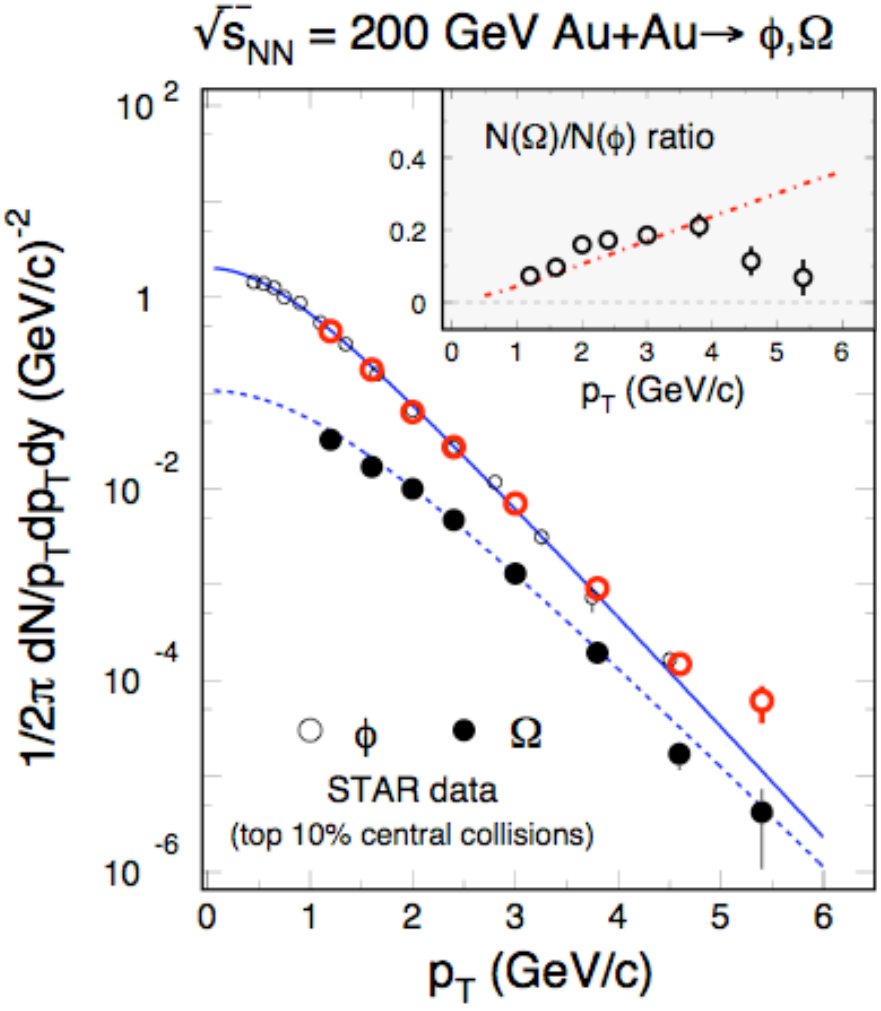
In Au + Au collisions:

(1) Partonic energy loss - tense interactions among partons

(2) Partonic collectivities and de-confinement

(3) Hadron yields in the state of equilibrium

Multi-strange Hadron Ratios



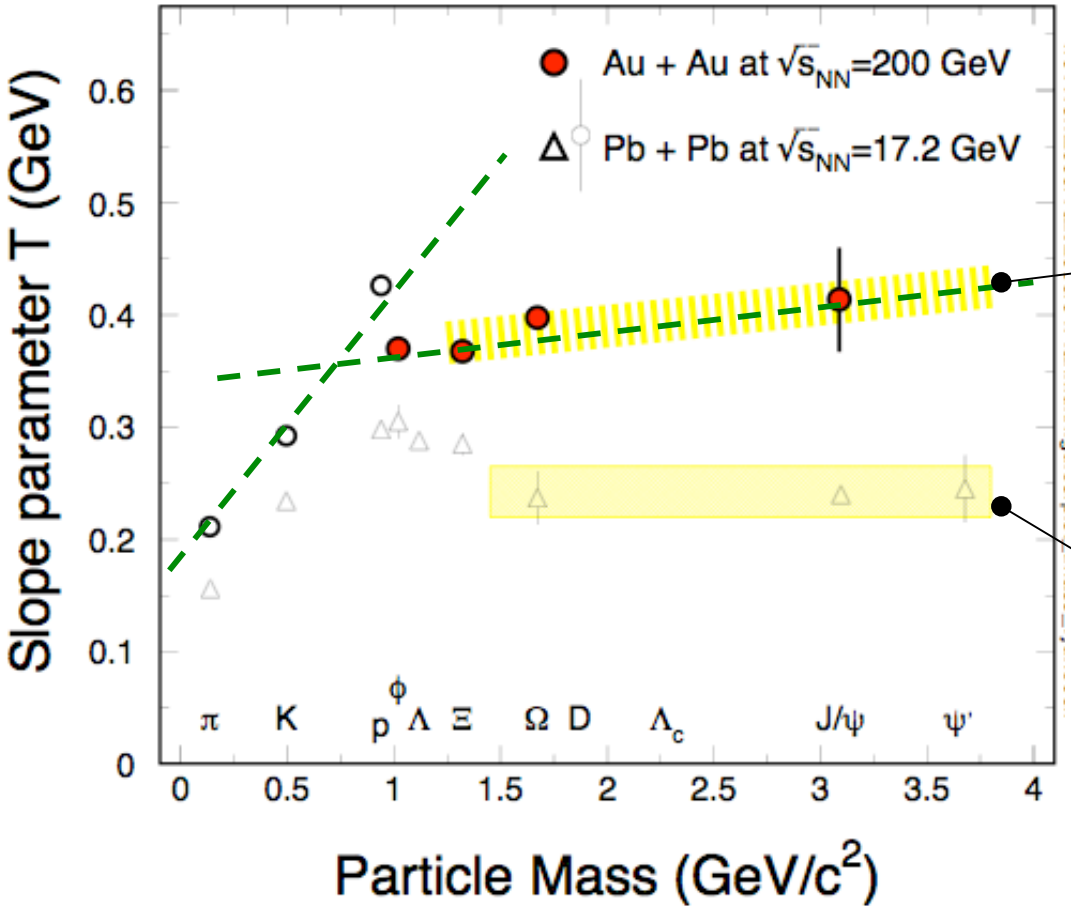
1) Up to p_T~ 4 GeV/c, both ϕ, Ω spectra are exponential

2) In heavy ion collisions at RHIC, up to p_T ~ 4 GeV/c, (*model predicts 8 GeV/c) the strangeness production is dominated by the thermal like processes.

**Hwa and Yang, nucl-th/0602024*
Chen and Ko, PRC73 (2006) 044903

STAR data: QM05/SQM06,
J. Chen, S. Blyth et al.

Slope Parameter Systematics



RHIC results:
Collective motion for multi-strange and charm hadrons!

$\langle\beta_p\rangle \geq 0.2c$

SPS results:
No collective motion for multi-strange and charm hadrons!

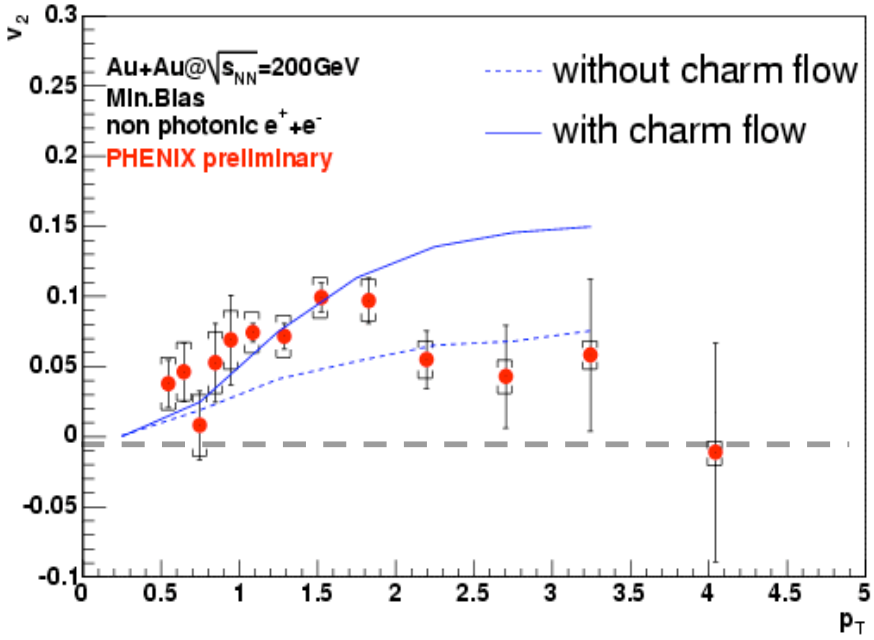
At RHIC, φ, Ξ, Ω, and J/ψ show collective motion in 200 GeV Au + Au central collisions!

PHENIX (π, K, p, J/ψ): PRC69, 034909(04), QM05; STAR (φ, Ξ, Ω): QM05.

New Results from RHIC

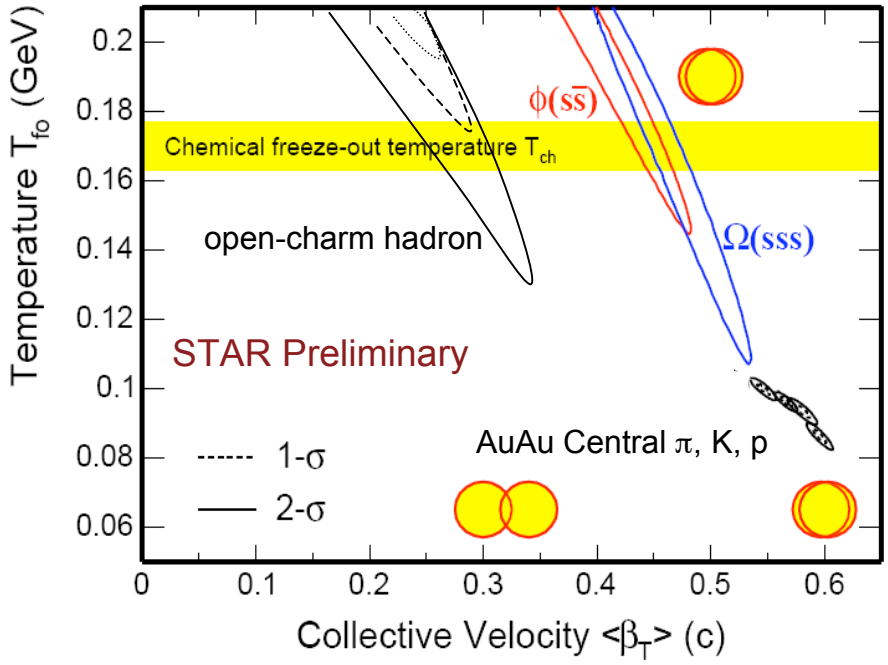
Non-photonic electrons:

taken from S. Esumi (SQM06)



Open-charm hadron spectra:

taken from Y. ZHang (SQM06)

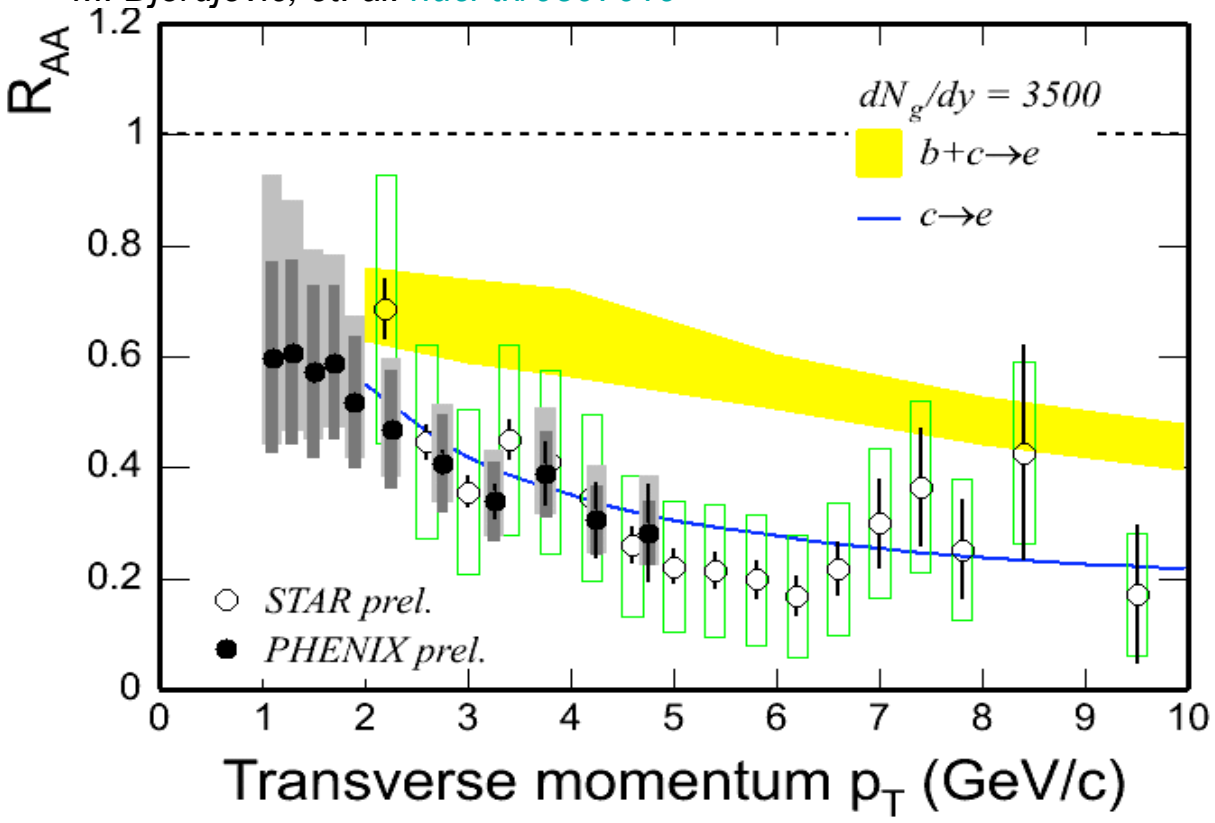


1) Data prefers charm (heavy-flavor) hadrons flow
2) Interaction of colored-resonances at near T_c?

*Greco, Ko, Rapp PL**B595** ,202(04)*

Heavy Flavor Hadron Energy Loss

M. Djordjevic, et. al. nucl-th/0507019



1) Non-photonic electrons decayed from - charm and beauty hadrons

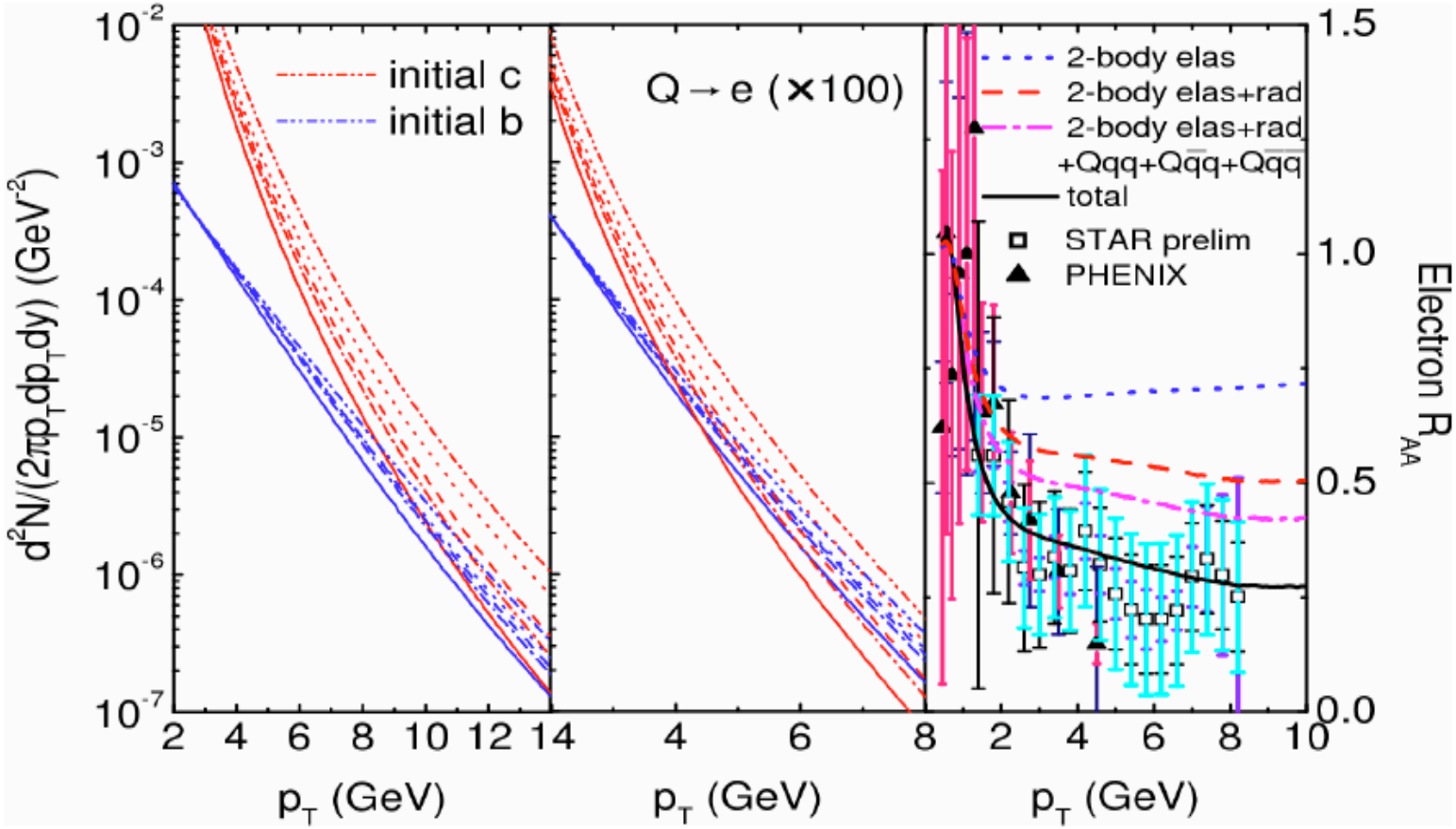
2) At $p_T \geq 6$ GeV/c,

$R_{AA}(n.e.) \sim R_{AA}(h^{\pm})$

contradicts to naïve pQCD predictions

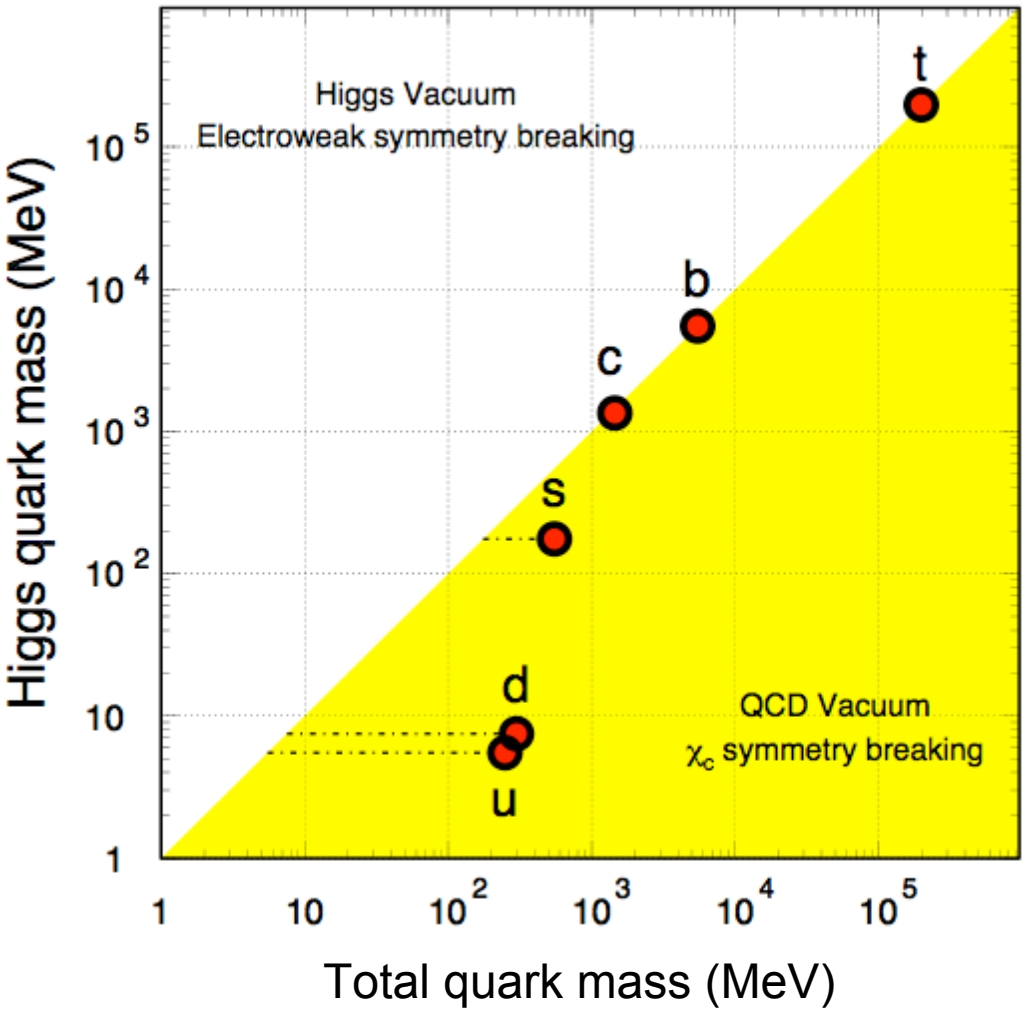
Surprising results -
- challenge our understanding of the energy loss mechanism
- force us to RE-think about the collision energy loss
- requires isolation of c-hadrons contributions from b-hadrons

Three-body Elastic Scatterings



Chen & Ko (nucl-th/0602025):
- Three-body elastic ~ two-body radiative+elastic scattering
- How about other many-body interactions?

Quark Masses



1) Higgs mass: electro-weak symmetry breaking. (current quark mass)
2) QCD mass: Chiral symmetry breaking. (constituent quark mass)

⇨ Strong interactions do not affect heavy-quark masses.

⇨ Important tool for studying properties of the hot/dense medium at RHIC.

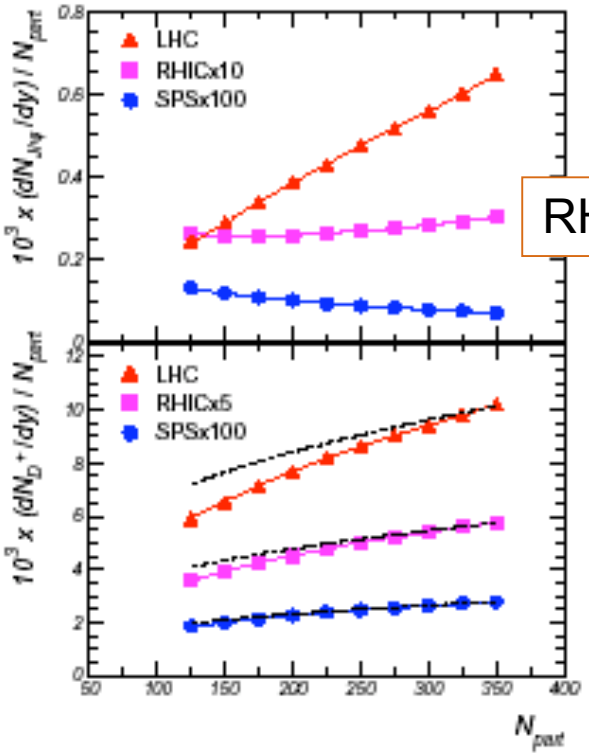
⇨ Test pQCD predictions at RHIC.

Open-/Closed-charm Hadron Yields

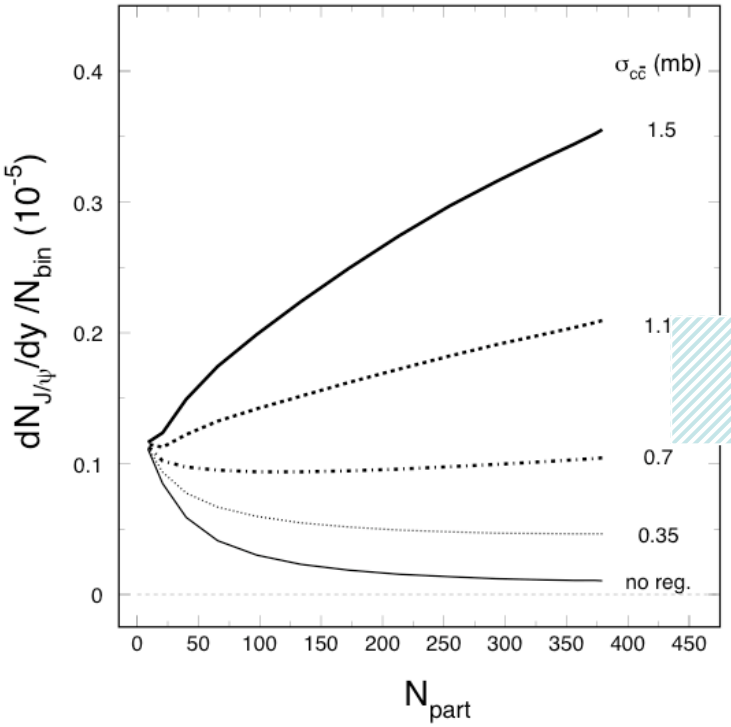
A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, Phys.Lett. **B571** , 36(03).

T. Matsui and H. Satz, Phys. Lett. **B178**, 416(1996).
L. Grandchamp and R. Rapp, Phys. Lett. **B523** , 60(01).

R. Thews, M. Schroedter, J. Rafelski, Phys. Rev. **C63** 054905(01).



RHIC

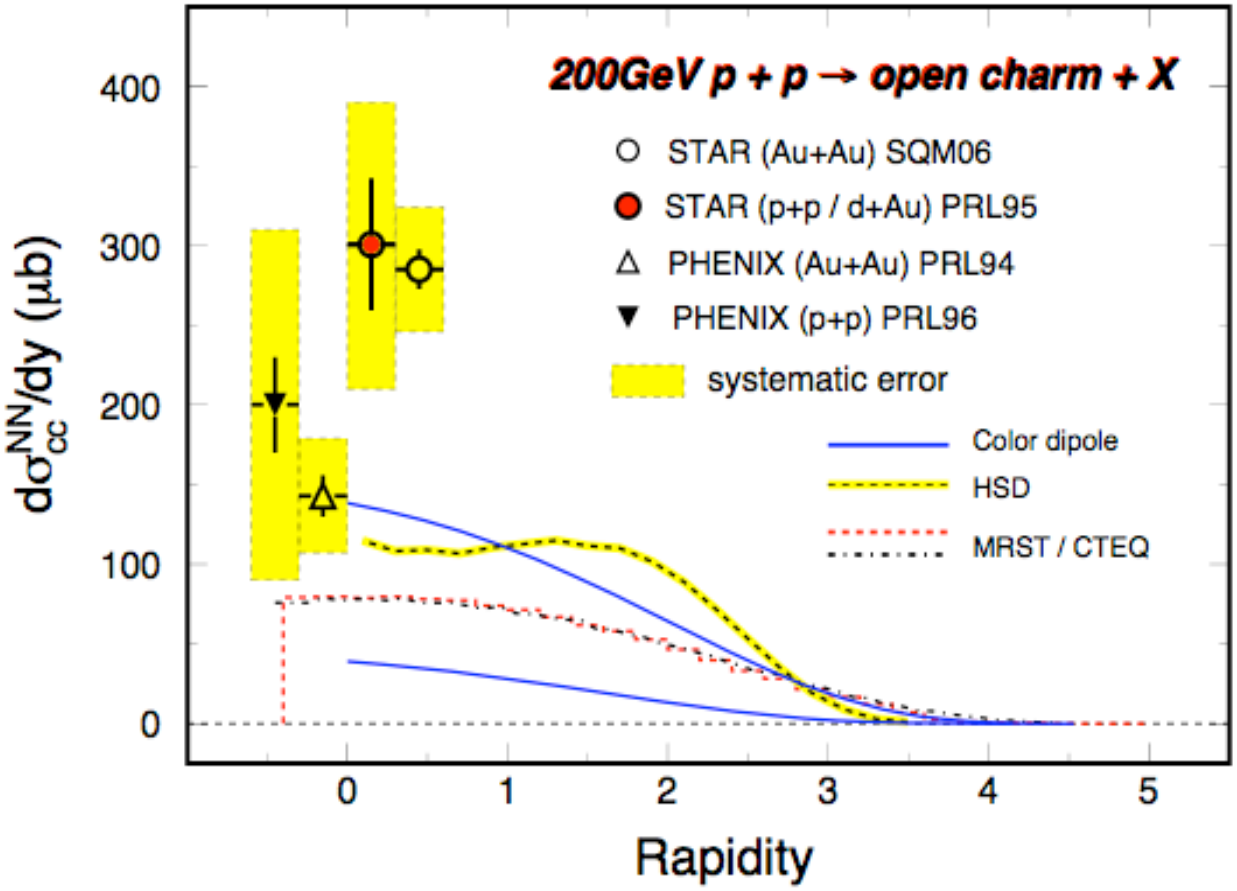


RHIC

(1) open charm cross sections
(2) direct pQCD production
(3) medium effects (χ properties)
(4) absorption (color screening)

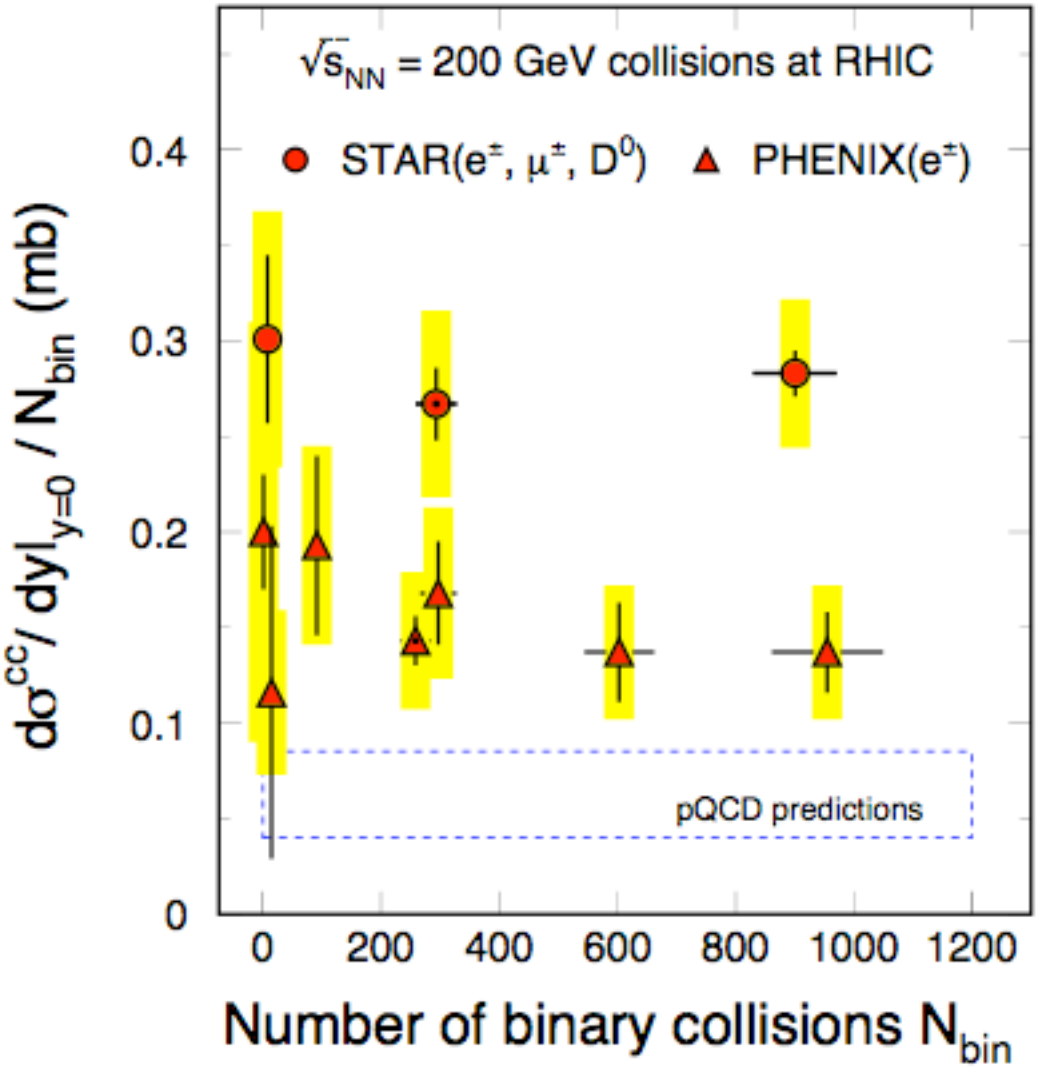
Model results are different, centrality dependence measurements are important!

Charm Cross Sections at RHIC



1) Large systematic uncertainties
2) Theory under predict
   STAR ~ 2 x PHENIX

Charm Cross-section vs. N_{bin}



dσ(cc)/dy at RHIC

1) Within error bars, N_{bin}-scaling is observed!

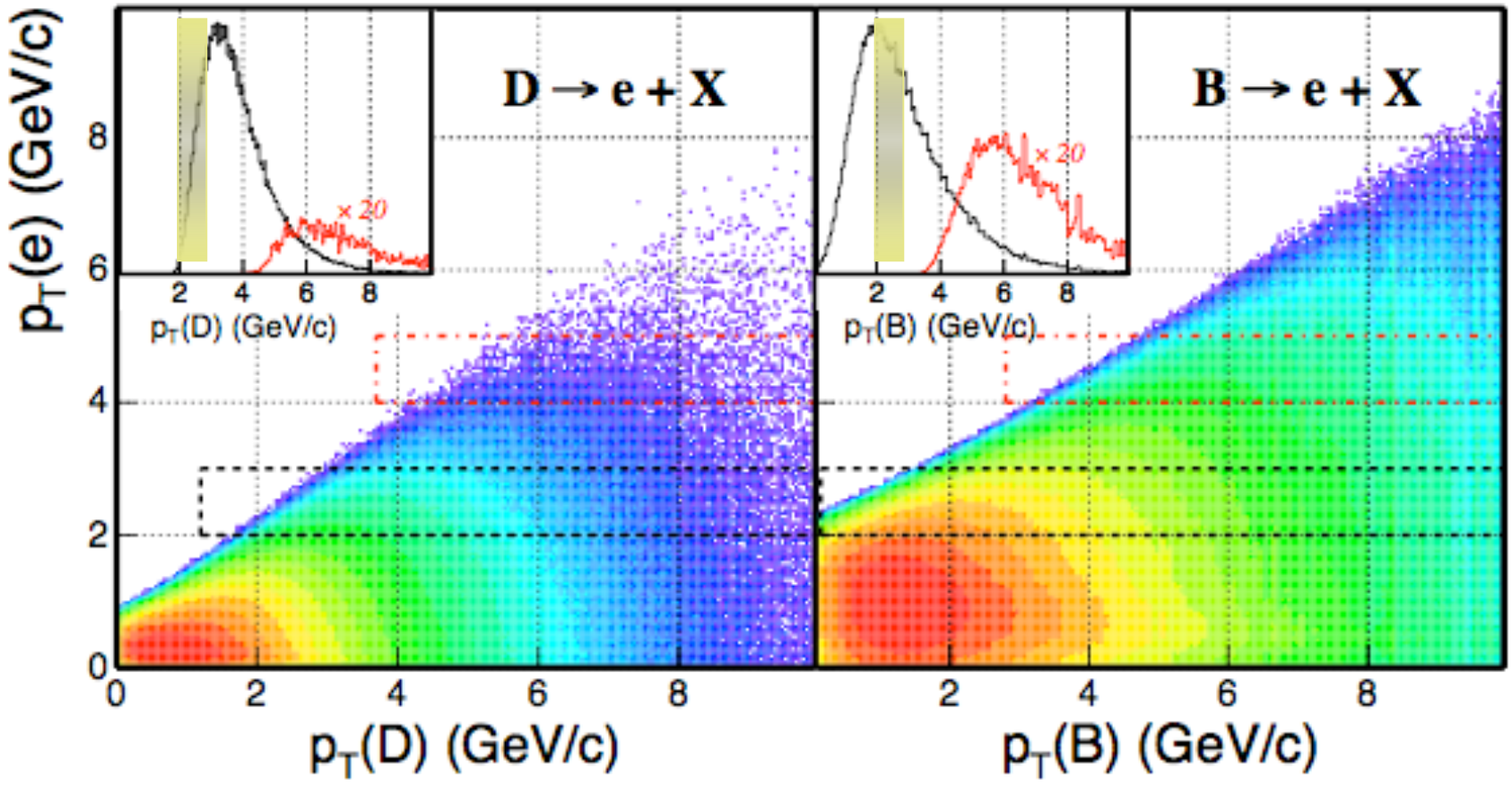
2) Large systematic uncertainties

3) Theory under predict

4) dσ(cc)/dy at RHIC:

   STAR ~ 2 x PHENIX

Decayed Electron p_T vs. c- and c-hadron p_T



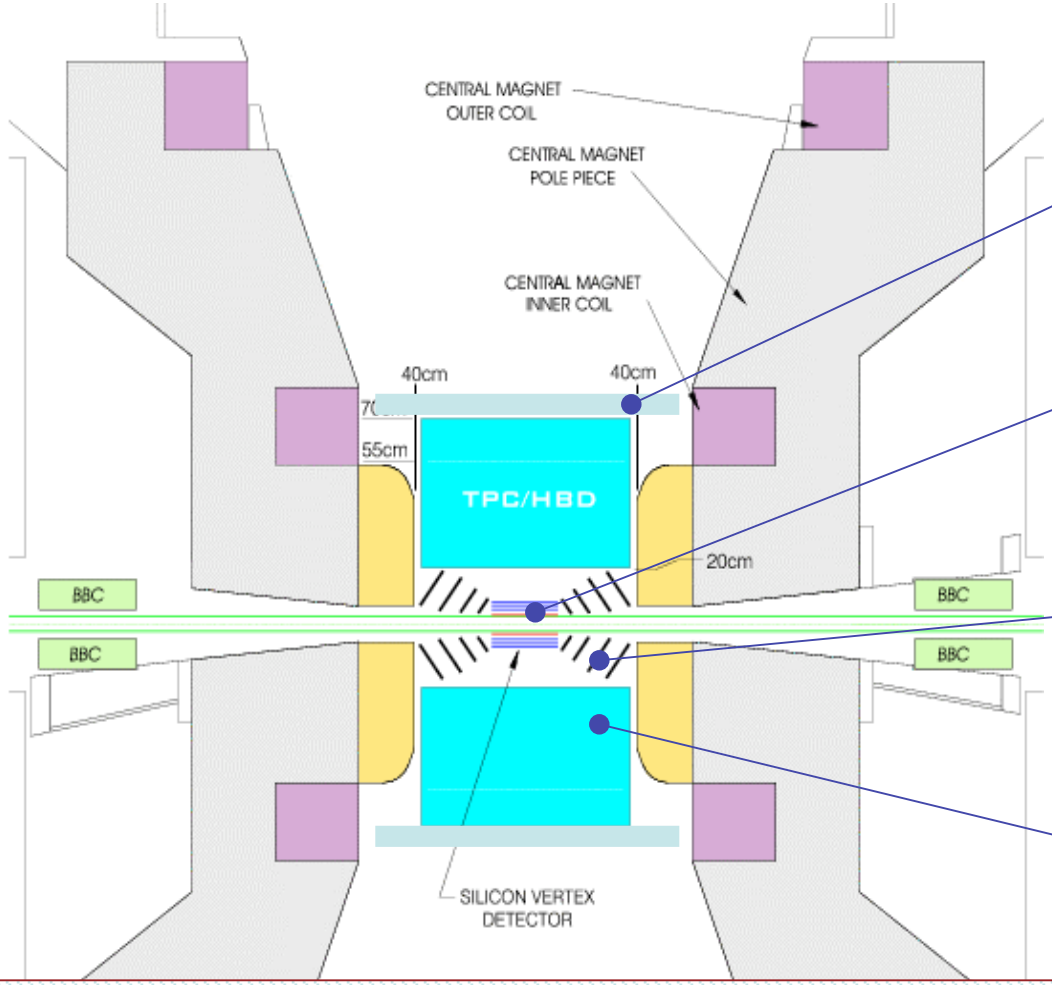
The correlation between the decayed electrons and heavy-flavor hadrons is weak.

Pythia calculation Xin Dong, USTC October 2005

Upgrades Are Needed!

When systematic error dominates the data, new experiments (detectors) are called for.

PHENIX Upgrades



GEM
$|\eta| \leq 0.7$

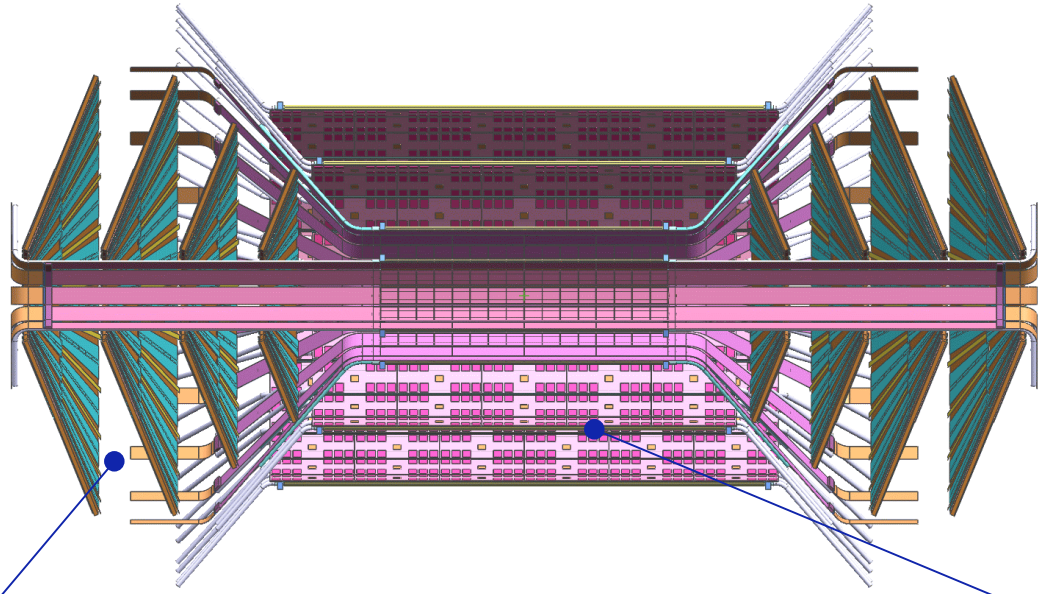
Barrel VTX
$|\eta| \leq 1.2$

Endcap VTX
$1.2 \leq |\eta| \leq 2.7$

HBD

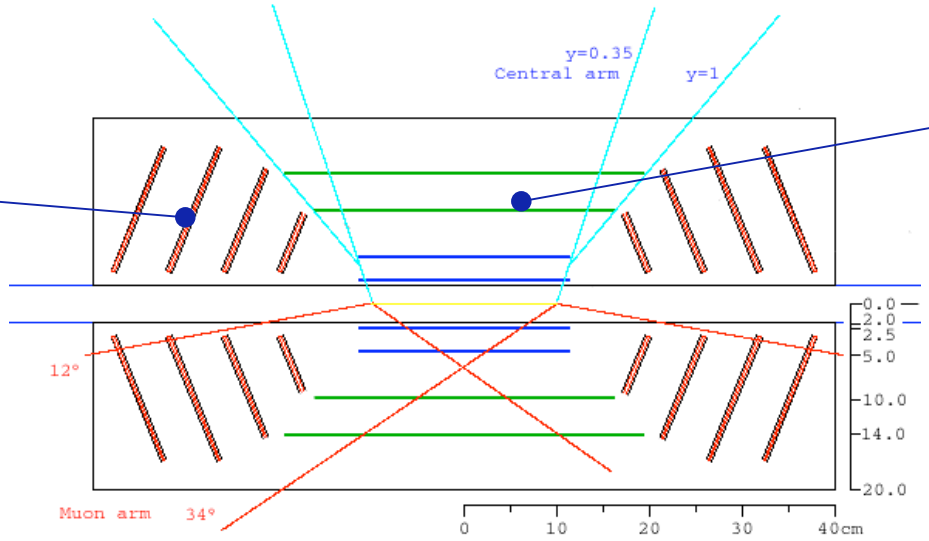
Provide displaced vertex & jets measurement over ~ 2π

PHENIX Silicon Vertex Trackers

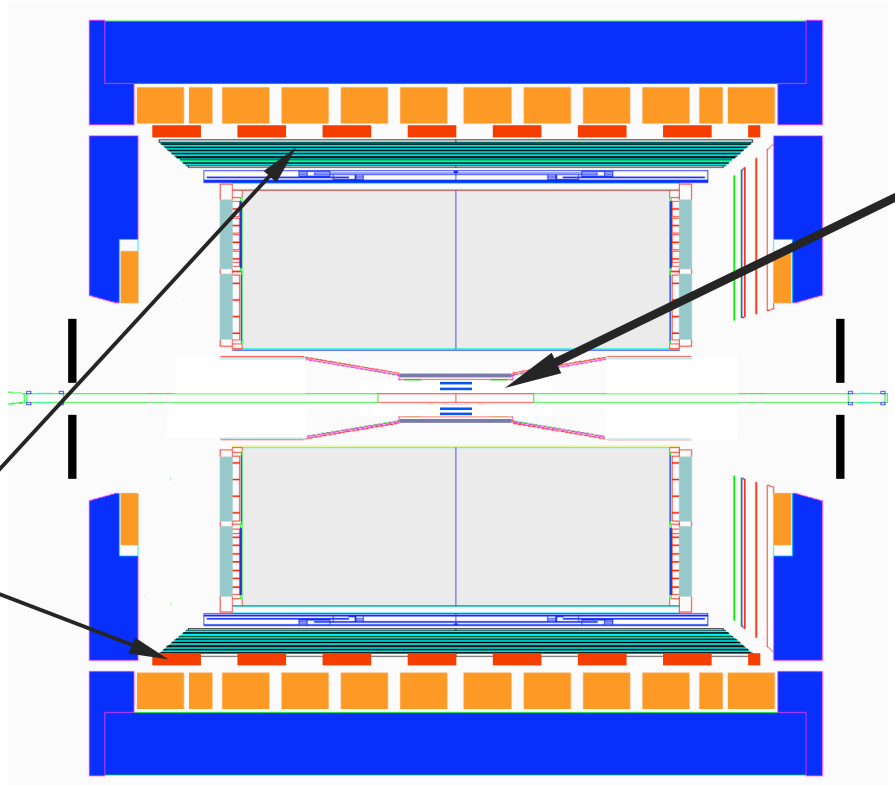


F-VTX endcap

Si-VTX barrel



STAR Upgrades



HFT: 2 layers of Si at mid-y
Finish: 2010

STAR MRPC ToF:
$\Delta\varphi=2\pi$ at mid-y
Finish: 2008

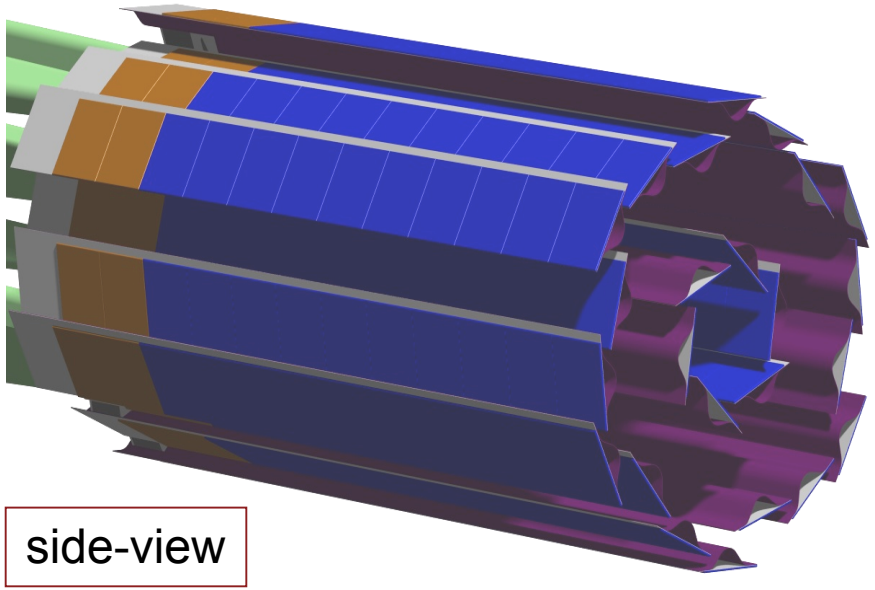
1) Precision tracking detector: ≤ 8 μm single hit resolution

2) Topologically reconstructing charm-hadrons

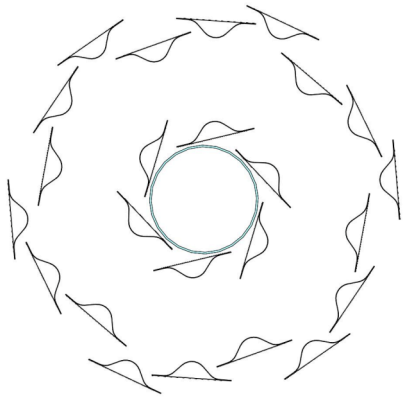
3) Analyze charm-hadron **flow** ($\mathbf{v_2}$) and **energy loss** ($\mathbf{R_{AA}}$)

The HFT Mechanical Design

- Two Layers of Si
  - 1.5 cm radius
  - 5 cm radius
- High Resolution
  - 100M pixels
  - 30 x 30 μm^2
- Thin – with low MCS
  - 50 μm thinned Si
  - 0.28% radiation length
  - 0.5 mm beam pipe
  - CMOS technology
- 24 Ladders
  - 10 chips, 2 x 20 cm^2
  - 100 mW/cm^2 power budget
  - air cooled

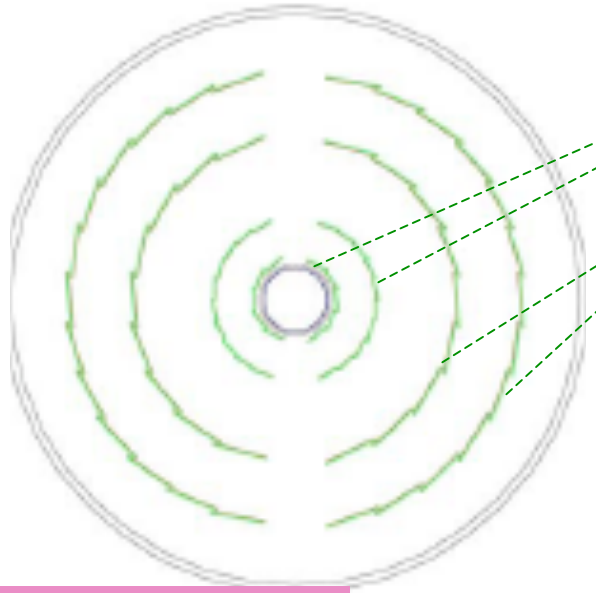


side-view



end-view

Beam Views

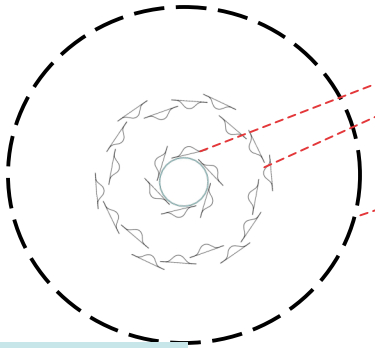


- 2-layer Si hybrid pixels: $x/x_0 \sim 1.2\%$;
  2.5cm inner radius; fast readout
- 2-layer Si strips, $x/x_0 \sim 2\%$

$|\eta| \le 1.2$

$p_T \le 2$ GeV/c	$e^{\pm}$
$2 < p_T \le 6$ GeV/c	D-mesons…
$1 < p_T \le 6$ GeV/c	$B \rightarrow J/\psi$

PHENIX VTX



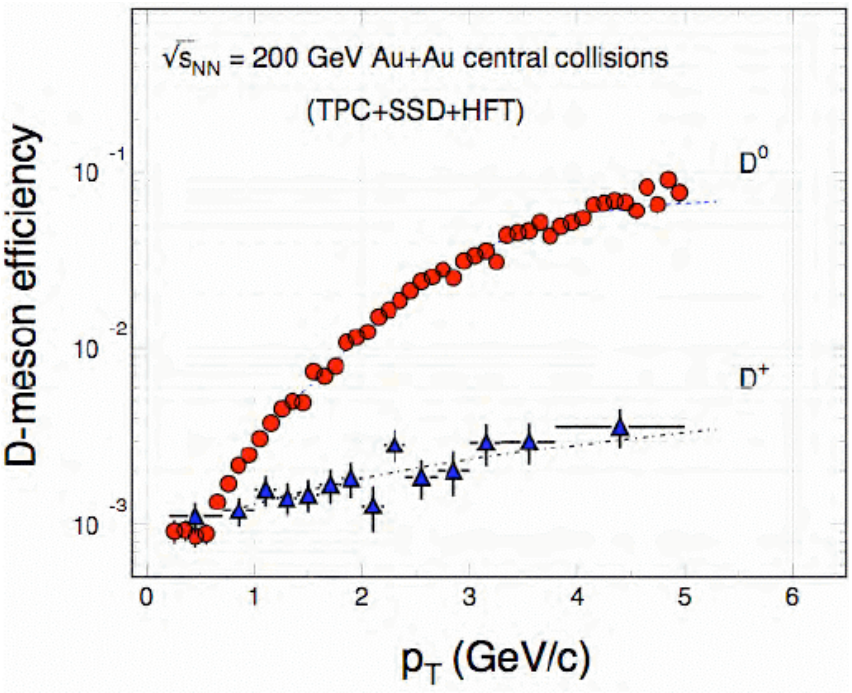
- 2-layer CMOS: $x/x_0 \sim 0.28\%$;
  1.5cm inner radius; 200μs integration
- 1-layer* Si strip

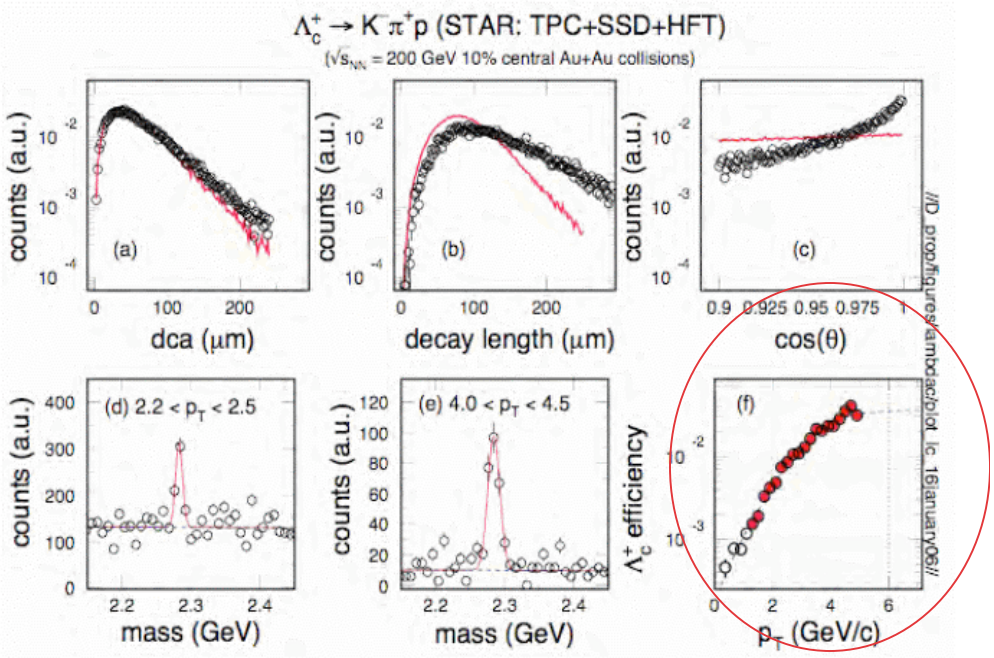
$|\eta| \le 1$

$p_T > 0.5$ GeV/c	e, $D^{0,\pm,s,*}$, Λ_c ..
D-D correlation functions	

STAR HFT

C-hadron Reconstructions





1) **D^0, D_s, D^+, Λ_c** and their anti-particles can be reconstructed with the combination of the HFT+SSD*+TOF+TPC.

2) Decent reconstruction efficiencies at low p_T region - important for flow analysis.

3) PHENIX VTX-barrel: reconstruct D at $p_T \geq 2$GeV/c

Rates Estimate - v_2

(a) dN/dp_T distributions for D-mesons.

Scaled by $<N_{bin}> = 290$, corresponds to the minimum bias Au + Au collisions at RHIC.

(b) Assumed v_2 distributions for D-mesons.

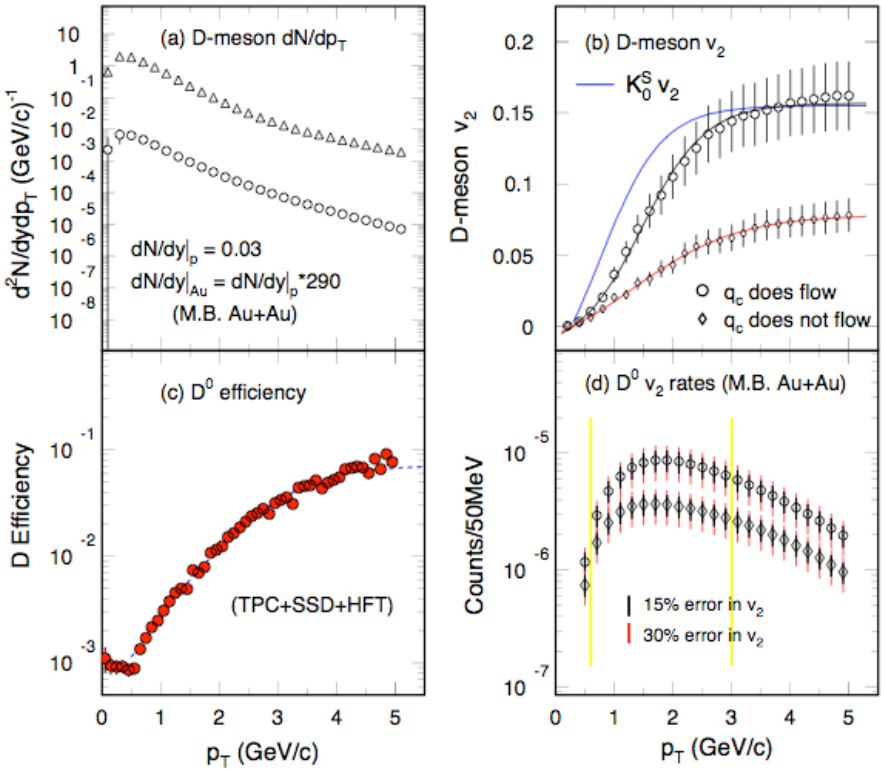
---- PLB 595, 202 (2004)

Error bars shown are from 15% systematic errors

(c) 3-σ significance D^0 efficiency with TPC+SSD+HFT.

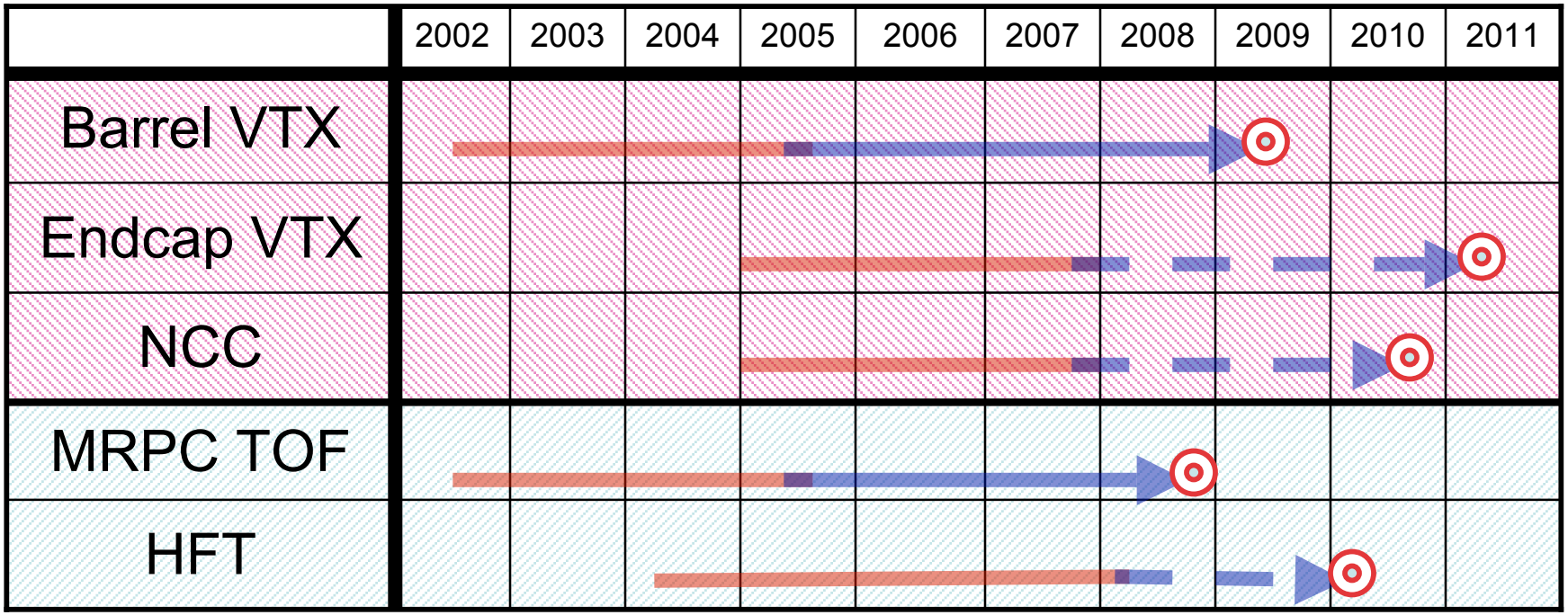
(d) D^0 meson v_2 rates from minimum bias Au + Au collisions at 200 GeV.

The small and large error bars are for 15% and 30% systematic errors, respectively. For the v_2 analysis, 12 bins in φ are used.



p_T (GeV/c)	Δp_T (GeV/c)	# of Events q_c does flow	# of Events q_c does not flow
0.6	0.2	260×10^6	525×10^6
~~1.0~~	~~0.5~~	~~70×10^6~~	~~140×10^6~~
2.0	0.5	53×10^6	125×10^6
3.0	1.0	105×10^6	175×10^6
5.0	1.0	210×10^6	440×10^6

Heavy Flavor Upgrades at RHIC



R&D phase

Construction phase

Ready for data

solid: Approved proposal

PHENIX

STAR

Summary

1) RHIC heavy flavor upgrades finish at 2010:

- high p_T c-hadron spectra

  ⇨ pQCD properties in hot/dense medium

- precise data on total cross section for c- and b-hadrons
- c-hadron correlation functions and flow

  ⇨ heavy flavor collectivity and light flavor thermalization

- surprises: charm R_{AA} data surprised us, more to come.

  ⇨ **New era for understanding the medium properties at RHIC is coming.**

2) Theory: Predictions on for c- and b-hadron distributions separately.

QCD Phase Diagram